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PATENT APPLICATION

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Date of Deposit: August 24, 1999

Signature: Kevin M. Mason

TITLE Distributed Dynamic Channel Allocation Technique For Multi-Carrier CDMA Cellular Systems With Mobile Base Stations

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SIR:

Enclosed are the following papers relating to the above-named application for patent:

Specification
10 Sheets of informal drawing(s)
Declaration and Power of Attorney
1 Assignment with Cover Sheet

CLAIMS AS FILED				
	NO. FILED	NO. EXTRA	RATE	CALCULATIONS
Total Claims	26-20 =	6	X \$18 =	\$108
Independent Claims	8-3 =	5	X \$78 =	\$390
Multiple Dependent Claim(s), if applicable			\$260 =	\$0
Basic Fee				\$760
			TOTAL FEE:	\$1,258

Please file the application and charge **Lucent Technologies Deposit Account No. 12-2325** the amount of \$1,258.00, to cover the filing fee. *Duplicate copies of this letter are enclosed.* In the event of non-payment or improper payment of a required fee, the Commissioner is authorized to charge or to credit **Deposit Account No. 12-2325** as required to correct the error.

Please address all correspondence to: Kevin M. Mason, Ryan & Mason, L.L.P., 90 Forest Avenue, Locust Valley, New York 11560. Telephone calls should be made to the under-signed attorney at (203) 255-6560.

Respectfully,

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DISTRIBUTED DYNAMIC CHANNEL ALLOCATION TECHNIQUE FOR MULTI-CARRIER CDMA CELLULAR SYSTEMS WITH MOBILE BASE STATIONS

5 **Field of the Invention**

The present invention relates to multi-carrier CDMA cellular systems, and more particularly, to a distributed dynamic channel allocation algorithm for multi-carrier CDMA cellular systems with mobile base stations.

10 **Background of the Invention**

Code division multiple access (CDMA) techniques transmit multiple information signals on the same channel (carrier frequency), and differentiate each user sub-channel by encoding it with a unique spreading code. Code division multiple access (CDMA) techniques have been employed in many digital wireless communication systems to permit a large number of system users to communicate with one another. CDMA systems treat each user as a separate signal, while treating other users as either interference or noise. As the number of interfering users increases, the corresponding interferences add to cause degradation of performance, such as an increasing bit error rate (BER) or frame error rate.

Multi-carrier CDMA systems are employed for interference avoidance rather than interference averaging. Interference avoidance is more plausible when interfering terminals are likely to get close to each other frequently; a situation which arises in a highly dynamic network such as a cellular network with mobile base stations. In fact, the case of mobile base stations is typical for battlefield networks where a number of Radio Access Points (RAPs) serve as the base station and are deployed in the field to act as switching/routing nodes for traffic generated by mobile terminals in the vicinity of such RAPs. In a commercial setting, it has been proposed to deploy RAPs on trucks or public transportation vehicles, such as buses and the like.

While conventional channel allocation techniques are satisfactory for fixed or stationary base stations, the mobility of the base stations themselves degrades the performance of such conventional channel allocation techniques in the mobile environment of the present invention. Thus, a need exists for a distributed dynamic channel allocation algorithm for multi-carrier CDMA cellular systems having mobile base stations.

Summary of the Invention

Generally, a distributed dynamic channel allocation algorithm is disclosed for a multi-carrier CDMA cellular system having at least one mobile base station. The disclosed distributed dynamic channel allocation algorithm is based on channel power measurements carried out by both the mobile station requesting an allocation of a resource and the mobile base station attempting to allocate an available resource to the mobile station. Channel power measurements from both the mobile base station and the requesting mobile station are used since the mobile base station are not fixed base stations as is the case in commercial CDMA systems.

The distributed dynamic channel allocation algorithm attempts to allocate the best available resource for the requesting mobile station, in terms of interference, while minimizing the amount of interruption that the allocated resource may cause to existing connections in neighboring cells. Thus, the distributed dynamic channel allocation algorithm follows a "least-interference, least-interruption" strategy. The distributed dynamic channel allocation algorithm of the present invention is load balancing, since it tends to assign new resources to mobile base station with lighter loads. Due to the mobility of the mobile base station, a mobile base station can cause interference to mobiles connected to another close-by mobile base station. According to another aspect of the invention, the uplink and downlink channels are not paired and can be independently assigned to requesting mobile stations.

Dynamic channel allocation processes are provided to assign resources to a new mobile station, and to assign a new resource to an existing mobile station. The dynamic channel allocation process (new mobile) and dynamic channel allocation process (new resource for existing mobile) process collected measurement information on network interference and load conditions, and assign a resource to a requesting mobile station in an optimum manner.

A more complete understanding of the present invention, as well as further features and advantages of the present invention, will be obtained by reference to the following detailed description and drawings.

Brief Description of the Drawings

FIG. 1 illustrates a multi-carrier CDMA cellular system that includes a mobile base station and a mobile station in accordance with the present invention;

FIG. 2 is a sample table from an exemplary load table of FIG. 1;

FIG. 3 is a sample table from an exemplary user list of FIG. 1;

FIG. 4 is a sample table from an exemplary nominal resource availability table of FIG. 1;

FIG. 5 is a sample table from an exemplary measured resource availability table of FIG. 1;

FIG. 6 is a sample table from an exemplary realistic resource availability table of FIG. 1;

FIG. 7 is a sample table from an exemplary mobile base station (RAP) neighborhood received power list of FIG. 1;

FIG. 8 is a sample table from an exemplary demand list of FIG. 1;

FIG. 9 is a sample table from an exemplary probability of assignment table of FIG. 1;

FIG. 10 illustrates circular buffers used by the mobile base station of FIG. 1;

FIG. 11 is a sample table from an exemplary downlink interference measurement table of FIG. 1;

FIG. 12 is a sample table from an exemplary predicted new load table of FIG. 1;

FIG. 13 is a sample table from an exemplary neighborhood queue size list of FIG. 1;

FIG. 14 is a sample table from an exemplary considerate availability table of FIG. 1;

FIG. 15 is a sample table from an exemplary predicted resource availability table of FIG. 1;

FIGS. 16A and 16B, collectively, are a flow chart describing an exemplary dynamic channel allocation process (new mobile) performed by the mobile base station of FIG. 1;

FIG. 17 is a sample table from an exemplary mobile-estimated availability tables of FIG. 1;

FIG. 18 is a sample table from an exemplary total availability table of FIG. 1; and

FIG. 19 is a flow chart describing an exemplary dynamic channel allocation

process (new resource for existing mobile) performed by the mobile base station of FIG. 1.

Detailed Description

FIG. 1 illustrates a multi-carrier CDMA cellular system that includes a mobile base station 100 and a mobile station 150, in accordance with the present invention. According to one feature of the present invention, the distributed dynamic channel allocation algorithm is based on channel power measurements carried out by both the mobile station requesting an allocation of a resource and the mobile base station 100 attempting to allocate an available resource to the mobile station. Since the mobile stations play a role in obtaining a resource allocation, based on information they receive from the mobile base stations 100, the resource allocation is improved. A resource is defined as one PN code over one frequency band and is equal to one CDMA channel. Channel power measurements from both the mobile base station 100 and the requesting mobile station are used since the mobile base station 100 are not fixed base stations as is the case in commercial CDMA systems.

Generally, the distributed dynamic channel allocation algorithm tries to capture the best available resource for the requesting mobile station, in terms of interference, while minimizing the amount of interruption that the allocated resource may cause to existing connections in neighboring cells. Thus, according to a further feature of the present invention, the distributed dynamic channel allocation algorithm follows a "least-interference, least-interruption" strategy.

In view of the mobility of the mobile base station 100, a mobile base station 100 can cause interference to mobiles connected to another close-by mobile base station 100. Thus, information from the second mobile base station 100 only, based on its loading, will not be sufficiently accurate and real measurements from the mobile stations of the affected cell have to be collected and taken into consideration. The distributed dynamic channel allocation algorithm of the present invention is load balancing, since it tends to assign new resources to mobile base station 100 with lighter loads.

MULTI-CARRIER CDMA MOBILE BASE STATION TERMINOLOGY

In the vicinity of a mobile, there are N RAPs denoted R_1 to R_N . The forward, or downlink is divided into L CDMA frequency bands, denoted B_1^D to B_L^D . The reverse, or uplink

is divided into L CDMA frequency bands, denoted B_1^U to B_L^U . According to another feature of the present invention, the uplink and downlink channels are not paired.

The mobile base stations 100 and mobile stations use a broadcast channel to announce their measurements, tables and decisions. The broadcast channel must be separate in frequency from traffic channels. Generally, a broadcast channel can be implemented by dedicating a small frequency band for such a purpose. The frequency band allocated for broadcast is then divided into a downlink portion and an uplink portion. The downlink portion is to be accessed by mobile base stations 100 and the uplink portion is to be accessed by mobile stations. Access to an uplink or downlink portion can be made through contention for PN codes or time slots.

The maximum amount of time that a mobile can wait before being allocated a resource is called the "wait period" and is equal to T_{wait} .

As shown in FIG. 1, each mobile base station 100 includes certain hardware components, such as a processor 120, a data storage device 130, and a transmit/receive section 140. The processor 120 can be linked to each of the other listed elements, either by means of a shared data bus, or dedicated connections, as shown in FIG. 1. The transmit/receive section 140 allows the mobile base station 100 to communicate with other mobile base stations 100 and mobile stations.

The data storage device 130 is operable to store one or more instructions, which the processor 120 is operable to retrieve, interpret and execute in accordance with the present invention. In addition, the data storage device 130 includes a number of tables, discussed hereinafter, that are used by the distributed dynamic channel allocation algorithm to allocate an appropriate resource to a requesting mobile station. Finally, the data storage device 130 includes a dynamic channel allocation process (new mobile) 1600 and a dynamic channel allocation process (new resource for existing mobile) 1900 discussed further below in conjunction with FIGS. 16 and 19, respectively. The manner in which each table is utilized in deriving a dynamic channel allocation will be discussed in conjunction with the flow charts of FIGS. 16 and 19.

MOBILE BASE STATION TABLES

Load Table

A mobile base station R_i forms, and continuously updates, a load table 200, shown

in FIG. 2. It is noted that since a mobile base station 100 is also referred to as a Radio Access Point (RAP), a variable, R_i , is used to identify a mobile base station 100. The load table 200 records $m_{l,i}^D$, the number of resources received from R_i over band l on the downlink and $m_{l,i}^U$, the number of resources transmitted to R_i over band l on the uplink.

User List

A mobile base station, R_i , keeps track of its users by maintaining a user list 300, shown in FIG. 3. The user list 300 records $C_{k,l}^{i,U}$, the set of PN codes used by mobile M_k for transmission over B_l^U for the mobile base station R_i , and $C_{k,l}^{i,D}$, the set of PN codes used by the mobile base station R_i for transmission to mobile M_k over band B_l^D . As discussed further below, a mobile station may use more than one code over a certain band, and also more than one band, in order to fulfil the rate requirements for the service in concern. It is noted that if a mobile station is using λ number of PN codes over a certain band, the mobile station is counted as λ users, for the corresponding band, when filling up the load table.

Nominal Capacity and Availability

Each RAP R_i assumes a nominal capacity, $CAP_{l,i}^U$ and $CAP_{l,i}^D$, for each band on uplink or downlink, respectively. The nominal capacity is usually determined prior to deployment of a mobile base station 100 as a result of simulations or field trials. In addition, a mobile base station R_i forms and continuously updates a nominal resource availability table 400, shown in FIG. 4, where:

$$a_{l,i}^{D,nom} = CAP_{l,i}^D - m_{l,i}^D, \text{ and}$$

$$a_{l,i}^{U,nom} = CAP_{l,i}^U - m_{l,i}^U.$$

Interference Measurements by Mobile Stations

Mobile stations connected to a mobile base station 100 periodically measure the downlink frequency bands and determine the amount of interference that exist on each band and send this information back to the mobile base station 100. These measurements do not necessarily require a separate channel for reporting to the mobile base station 100. The measurements can be reported by embedding them in the data sent by the corresponding mobile stations on their uplink channels.

The details of mobile downlink measurements are as follows. A mobile station measures the amount of interference power on each downlink frequency band. The mobile station translates the interference power into maximum number of new resources that can be added to the band without degrading the channel for the mobile. The translation from interference power to maximum number of new resources can be implemented as follows. For example, let the minimum S/I be η , the received power by mobile station M for a resource in the band in concern be P , the measured interference power be I and the amount of interference power due to a new resource (assuming the mobile base station 100 is transmitting at maximum power/resource) be Δ_I . Then, the maximum number of new resources determined by M for the band in concern is:

$$a \leq \min \left\{ CAP, \left\lfloor \frac{\left(\frac{P}{\eta} - I \right)}{\Delta_I} \right\rfloor \right\},$$

where $\lfloor \cdot \rfloor$ denotes the largest integer smaller than or equal to the enclosed quantity and CAP is the nominal capacity of the downlink band in concern.

Resource Availability Based on Reported Interference Measurements

A mobile base station R_i averages the measurements from the mobile stations to obtain a measured resource availability table 500, shown in FIG. 5. The averaging procedure can be made such that mobile stations experiencing a bad channel may get larger weights, or stronger votes, as follows. For example, if the maximum number of new resources, or availability, determined by a mobile for a band is a , and let CAP be the nominal capacity for that band, then the modified availability is $a_{\text{mod}} = 4a$ if $a \leq CAP/4$, $a_{\text{mod}} = 3a$ if $CAP/4 \leq a \leq CAP/2$, $a_{\text{mod}} = 2a$ if $CAP/2 \leq a \leq 3CAP/4$, and $a_{\text{mod}} = a$ if $3CAP/4 \leq a \leq CAP$.

Mobile base station R_i also measures the interference on each uplink band and determines measured availability figures in similar way to the downlink procedure. Notice that the actual load on the mobile base station 100 may not reflect availability accurately if the mobile base station 100 is receiving interference from mobile stations close to it but they belong to an adjacent mobile base station 100. Thus, the mobile base station 100 should measure the uplink.

In addition, a mobile base station R_i forms a realistic resource availability table 600, shown in FIG. 6, based on the lower of the measured and nominal availability values, as follows:

$$a_{l,i}^{D,real} = \min \{a_{l,i}^{D,mrd}, a_{l,i}^{D,nom}\}, \text{ and}$$

$$a_{l,i}^{U,real} = \min \{a_{l,i}^{U,mrd}, a_{l,i}^{U,nom}\}$$

Neighboring Mobile Base Stations

A mobile base station R_i keeps track of other mobile base stations 100 in the vicinity and their power levels. Thus, mobile base station R_i forms and continuously updates a mobile base station (RAP) neighborhood received power list 700, shown in FIG. 7. The power levels $P_{i \leftarrow j}$ set forth in the RAP neighborhood received power list 700 are received on beacon channels.

Demand List

Each mobile base station R_i forms a demand queue for the mobile stations requesting resources from that mobile base station 100. The mobile stations are lined up in the queue based on a first-come first-serve criterion. Such a criterion is easily implemented if it is assumed that a time-stamp is associated with each request. The demand queue size for R_i will be denoted Q_i^D and Q_i^U for downlink and uplink, respectively. The queue size may be larger than the number of users lined up, since one user may request more than one resource per uplink or downlink. In other words, Q_i is the total number of requested resources per direction rather than the total number of queued mobile stations.

If the queue size is equal to some value $Q_{i,max}^D$ or $Q_{i,max}^U$, all new requests are rejected until the queue size is reduced by one. A mobile base station R_i keeps track of the mobile stations lined up in the queue by maintaining a demand list 800, shown in FIG. 8.

Probability of Assignment Table

A mobile base station 100 keeps track of the statistics of each frequency band by computing the ratio between the number of resources successfully assigned to a band relative to the number of demands received by the mobile base station R_i . Thus, the mobile base station R_i forms and continuously updates a probability of assignment table 900, shown in FIG. 9.

The $p_{l,i}$ values set forth in FIG. 9 can be calculated such that old statistics are

dropped off. In other words, the mobile base station 100 forgets the statistics collected some time T ago, to provide better results due to the high dynamism of the system, as old results may be misleading and not representative of current situations. To enable the mobile base station 100 to forget old data, L circular buffers 1000, shown in FIG. 10, are utilized. As shown in FIG. 10, each circular buffer 1000 has β number of bits, for example, 1000 or 2^{10} bits (128 bytes). Clearly, β is the memory length. Each bit has a value of 1 or 0, depending on whether the resource at the time corresponding to that bit has been granted. When the buffer is full, new bits overwrite old ones as shown in FIG. 10. A probability, $p_{l,i}$, is then easily computed by counting the number of ones and dividing by β .

Interference Measurement Table

When a new resource request is received by a mobile base station R_i for a mobile M_k , the requesting mobile station informs R_i with the interference measurements the mobile has collected regarding the downlink, in the manner described above. These measurements are in the form shown in FIG. 11.

Predicted Load Table

A mobile base station R_i forms a predicted new load table 1200, shown in FIG. 12, for next new mobile station that requests resources. In one implementation, a predicted new load $\mu_{l,i}^D$ is computed as follows:

$$\mu_{l,i}^D = p_{l,i}^D \sum_{k=1}^K \lambda_k^D .$$

In one implementation, a predicted new load $\mu_{l,i}^U$ is computed as follows:

$$\mu_{l,i}^U = p_{l,i}^U \sum_{k=1}^K \lambda_k^U .$$

Neighborhood Predicted Load and Availability List

Adjacent RAPs keep track of predicted loads of each other as well as their realistic availabilities over all bands. For example, mobile base station R_i forms and continuously updates a neighborhood queue size list 1300, shown in FIG. 13.

In order for mobile base station R_i to limit the adjacent mobile base stations 100 from future interference with its existing load on the downlink, or receiving future interference

from adjacent mobile base station 100 loads on the uplink, R_i sends messages to all adjacent mobile base stations 100. The contents of these messages are availability estimates for the downlink/uplink bands based on the realistic availability table of R_i , the power level received at R_i due to the corresponding adjacent mobile base station 100 and the queue size of R_i relative to other adjacent mobile base stations 100 as well as R_i . The availability estimate sent by R_i to R_{ij} is calculated as follows: For band B_L^D on downlink, let the realistic availability for R_i be $a_{l,i}^{D,real}$.

Then, an approximate availability estimate from R_i to R_{ij} can be expressed as follows:

$$a_{l,D}^{i \rightarrow ij} = \gamma^{-1} \left(\frac{P_{i \leftarrow ij}}{P_{max}} \right)^{-1} \left(\frac{a_{l,ij}^{D,real} - \mu_{l,ij}^D}{\sum_{j=1}^J a_{l,ij}^{D,real} - \mu_{l,ij}^D} \right) \cdot (a_{l,i}^{D,real} - \mu_{l,i}^D) \cdot \alpha_{l,i}^D,$$

where $\alpha_{l,i}^D$ is a number between zero (0) and one (1) that is chosen according to the value of $(a_{l,i}^{D,real} - \mu_{l,i}^D)$. In other words, if $(a - \mu)$ is high, then $\alpha = 1$, and vice versa. It is noted that if $a_{l,ij}^{D,real} - \mu_{l,ij}^{D,real}$ is negative, it is replaced by zero.

The quantity P_{max} is the maximum total power transmitted by a mobile base station 100 per beacon. The factor γ is equal to the ratio of (interference power caused by a resource in a mobile base station 100 to a resource in another mobile base station 100) to (interference power caused by a resource in a mobile base station 100 to a resource in the same mobile base station 100) assuming equal received power levels per resource. That is, γ^{-1} indicates how many foreign resources, or users, are equivalent to a native resource. This concept is based on the assumption that within each mobile base station 100 cell, there are local PN codes assigned to resources and then wrapped (or multiplied by) in a PN code specific to the mobile base station 100. Clearly, $0 \leq \gamma < 1$.

For uplink, $a_{l,U}^{i \rightarrow ij}$ may be computed by having R_i listening to uplink bands using R_{ij} PN code and measure the power levels on each band. These power levels are $I_{ij}^{l,U}$. Also, R_i inquires the number of actual users on each band from R_{ij} , say $m_{l,ij}^U$ and computes the average power received at R_i due to a user under R_{ij} as $P_{l,ij}^{av} = \frac{I_{ij}^{l,U}}{m_{l,ij}^U}$. For example, the mobile base

station R_i then normalizes $P_{l,ij}^{av}$ to the average power per user in its cell to get $\bar{P}_{l,ij}^{av}$ and then computes:

$$a_{l,U}^{i \rightarrow ij} = (\bar{P}_{l,ij}^{av})^{-1} \gamma^{-1} \left(\frac{a_{l,ij}^{U,real} - \mu_{l,ij}^U}{\sum_{j=1}^J a_{l,ij}^{U,real} - \mu_{l,ij}^U} \right) \cdot (a_{l,i}^{U,real} - \mu_{l,i}^U) \cdot \alpha_{l,i}^U.$$

It should be mentioned that the scaling of the amount of availability, $a_{l,i}^{real}$, according to queue, or demand, sizes as well as availability is important in order to limit capacity of adjacent mobile base stations 100 in a fair way and at the same time leave some margin for R_i to accommodate new resources with priority to R_i , since availability for R_i is not scaled relative to demands or availability of other mobile base stations 100. The method of how adjacent mobile base stations 100 will make use of the availability estimate sent to them by R_i in order to account for R_i 's availability, or interference, limitations will be discussed next.

Considerate Resource Availability Table

Mobile base stations 100 collect estimates of availability tables from adjacent mobile base stations 100 and form a considerate availability table 1400, shown in FIG. 14. The considerate availability values shown in FIG. 14 are obtained as follows:

$$a_{l,i}^{D,con} = \min_{j=1, \dots, J} \{a_{l,D}^{ij \rightarrow i}\}, \text{ and}$$

$$a_{l,i}^{U,con} = \min_{j=1, \dots, J} \{a_{l,U}^{ij \rightarrow i}\}.$$

Predicted Resource Availability Table

A mobile base station R_i forms and continuously updates the final availability table, referred to as the predicted resource availability table 1500, shown in FIG. 15. The predicted resource availability table 1500 is applied to the next new mobile request. The predicted resource availability values shown in FIG. 15 are obtained as follows:

$$a_{l,i}^{D,pred} = \min\{a_{l,i}^{D,con}, (a_{l,i}^{D,real} - \mu_{l,i}^D)\}, \text{ and}$$

$$a_{l,i}^{U,pred} = \min\{a_{l,i}^{U,con}, (a_{l,i}^{U,real} - \mu_{l,i}^U)\}.$$

DISTRIBUTED DYNAMIC CHANNEL ALLOCATION PROCESSES

New Mobile

FIG. 16 is a flow chart describing an exemplary dynamic channel allocation process (new mobile) 1600. As shown in FIG. 16, the dynamic channel allocation process (new mobile) 1600 is initiated during step 1605 when a mobile station M_k broadcasts a request for a resource allocation with λ_k^U resources on uplink and λ_k^D resources on downlink.

Thereafter, during step 1610, the mobile base stations 100 that can hear M_k respond with their ID's and the received power levels at their antennas due to mobile, denoted $P_{M_k \rightarrow R_i}$. The mobile base stations 100 normalize the powers during step 1615 to some nominal value, which they are supposed to receive from a mobile's beacon in normal conditions. The normalized set of powers are then denoted $\bar{P}_{M_k \rightarrow R_i}$.

A mobile station only responds to mobile base stations 100 during step 1620 that are heard by the mobile station. Such response contains a list of RAP IDs for each mobile base station 100, such as R_1, \dots, R_N , the amount of required resources, such as λ_k^U and λ_k^D , and the downlink interference measurement table 1100.

During step 1625, the mobile also forms a table of potential mobile base stations 100 and the corresponding received power levels at the mobile's antenna due to the mobile base stations 100, denoted $P_{R_i \rightarrow M_k}$. The mobile station normalizes the powers during step 1630 to some nominal value, which it is supposed to receive from a mobile base station 100 beacon in normal conditions. The normalized set of powers are then denoted $\bar{P}_{R_i \rightarrow M_k}$.

Only the mobile base stations 100 that find their IDs listed, such as R_1, \dots, R_N , will consider the new request. All other mobile base stations 100 will ignore M_k 's request.

The mobile base stations 100 R_1, \dots, R_N , use the downlink interference measurement table 1100 sent by M_k as well as λ_k^U and λ_k^D for the next new mobile to appear, not for M_k . The mobile base stations 100 R_1, \dots, R_N respond to M_k during step 1635 with their most recent predicted resource availability tables 1500 along with the location of M_k in their queues. The mobile base stations 100 R_1, \dots, R_N also send their normalized received power levels $\bar{P}_{M_k \rightarrow R_i}$.

Mobile M_k forms a set of mobile-estimated availability tables 1700, shown in FIG. 17, during step 1640 for each mobile base station 100 R_1, \dots, R_N . For example, the mobile-estimated availability are obtained as follows:

$$a_{l,i}^{D,MobEst} = \bar{P}_{R_l \rightarrow M_k} \left(1 - \frac{I_{l,k}^D}{\sum_{l=1}^L I_{l,k}^D} \right) a_{l,i}^{D,pred}, \text{ and}$$

$$a_{l,i}^{U,MobEst} = \bar{P}_{M_k \rightarrow R_l} a_{l,i}^{U,pred}.$$

Mobile M_k then forms a total availability table 1800, shown in FIG. 18, where:

$$a_i^{D,total} = \sum_{l=1}^L a_{l,i}^{D,MobEst}, \text{ and}$$

$$a_i^{U,total} = \sum_{l=1}^L a_{l,i}^{U,MobEst}.$$

Mobile M_k picks the mobile base station(s) 100 during step 1645 that can provide all the required resources on both uplink and downlink, i.e., λ_k^U and λ_k^D , respectively. Mobile M_k then picks the mobile base station 100 with highest aggregate availability during step 1650, i.e., the mobile base station 100 with the highest $a_i^{U,total} + a_i^{D,total}$.

If M_k can not find a mobile base station 100 that satisfies all the resources on one or both of directions, it either terminates the resource allocation procedure and announces that, or it may reduce the requirement by one during step 1655 and repeat the previous step. In an alternate implementation, mobile M_k picks the mobile base station(s) 100 during step 1645 in a manner that distributes the required resources over all mobile base stations 100 (filling more available first). In this manner, resources are distributed over several mobile base stations 100 for "diversity" gain. However, it is noted that the algorithm in this case is not as load balancing as the primary embodiment.

If the mobile M_k decides on a mobile base station(s) 100 during step 1650, it announces the mobile base station(s) 100 selection during step 1660. All other mobile base stations 100 drop M_k off their queues and update availability tables accordingly during step 1665. The successful mobile base station(s) 100 keep(s) M_k in its queue, as if M_k did not decide yet, until all requests ahead of M_k are processed and then it allocates M_k the required resources and updates the tables during step 1670. If by the time M_k is first in the queue, not enough resources

are available (they have, been consumed by requests ahead of M_k), mobile M_k may choose to accept a lesser amount of resources and may get a higher priority in terms of being allocated the remaining amount of resources in the future, or M_k may choose to be rejected and program control will return to 1605 and continue in the manner described above. If M_k decides on mobile base station(s) 100, the successful mobile base station(s) 100 allocate(s) M_k the resources according to the corresponding entries in the mobile-estimated availability table 1700, i.e., M_k informs the mobile base station(s) 100 of which resources go to which bands. This is done by filling bands with the largest availability first and so on.

Until mobile M_k makes a decision, all concerned mobile base stations 100 wait for M_k and cannot process requests which came after M_k . However, a mobile base station 100 cannot wait for M_k more than the time it takes until M_k is first in the queue. If a mobile base station 100 does not receive a decision from M_k by that time, it drops M_k off its queue and announces the removal and also updates the availability tables accordingly.

If M_k is first in the queue of some mobile base station 100, such mobile base station 100 cannot wait for M_k 's decision more than a certain fixed amount of time. Thus, the mobile base stations 100 will not wait indefinitely for mobile stations.

FIG. 19 is a flow chart describing an exemplary dynamic channel allocation process (new resource for existing mobile) 1900. As shown in FIG. 19, the dynamic channel allocation process (new resource for existing mobile) 1900 is initiated during step 1910 when a mobile M_k requests an additional resource from its mobile base station 100. The mobile base station 100 waits until all requests ahead of M_k in the queue are processed. The mobile base station 100 then assigns M_k the requested resources during step 1920 according to the mobile-estimated availability table 1700. It is noted that in this case the mobile M_k only receives information from its mobile base station 100. That is, the mobile-estimated table 1700 consists of only two columns for uplink and downlink. If no resources are available, mobile M_k 's request may be turned down or M_k may be scheduled for a later time with higher priority, for example, during step 1930.

If a mobile M_k , or its mobile base station 100 or both, decide that a handoff is needed, the mobile M_k initiates the dynamic channel allocation process (new mobile) 1600.

However, M_k keeps the connection with its current mobile base station 100 until the mobile M_k is assigned a new mobile base station 100.

It is to be understood that the embodiments and variations shown and described herein are merely illustrative of the principles of this invention and that various modifications
5 may be implemented by those skilled in the art without departing from the scope and spirit of the invention. For example, the algorithm presented here can also be adjusted to apply to TDMA/CDMA systems, as would be apparent to a person of ordinary skill in the art.

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I claim:

1. A method for allocating a resource to a mobile station in a wireless
5 communications network having at least one mobile base station, said method comprising the steps of:

collecting measurements of interference and load in said wireless communications network, wherein said collected measurements include nominal resource availability information and measured resource availability information;

10 processing said collected information to identify a resource for said mobile station; and

assigning said resource to said mobile station.

2. The method of claim 1, wherein said measurements are collected from both said mobile station and said base stations.

3. The method of claim 1, wherein said nominal resource availability information provides a measure of the load on said wireless communications network.

4. The method of claim 1, wherein said measured resource availability information provides a measure of the interference on said wireless communications network.

5. The method of claim 1, wherein said nominal resource availability is a nominal capacity value for each band on said network less the number of users on said band.

25 6. A method for allocating a resource to a mobile station in a wireless communications network having a plurality of base stations including at least one mobile base station, said method comprising the steps of:

collecting measurements of interference and load in said wireless communications network, wherein said collected measurements include received power measurements from neighboring base stations;

processing said collected information to identify a resource for said mobile station; and
assigning said resource to said mobile station.

7. The method of claim 6, wherein said power measurements are received from said neighboring base stations on a beacon channel.

8. The method of claim 6, wherein said received power measurements provide an indication of the distance to a neighboring base station.

9. The method of claim 6, wherein said measurements are collected from both said mobile station and said base stations.

10. A method for allocating a resource to a mobile station in a wireless communications network having a plurality of base stations including at least one mobile base station, said method comprising the steps of:

collecting measurements of interference and load in said wireless communications network, wherein said collected measurements include predicted new load information;

processing said collected information to identify a resource for said mobile station; and

assigning said resource to said mobile station.

11. The method of claim 10, wherein said predicted new load, $\mu_{l,i}^D$, is computed as follows:

$$\mu_{l,i}^D = p_{l,i}^D \sum_{k=1}^K \lambda_k^D .$$

12. A method for allocating a resource to a mobile station in a wireless communications network having a plurality of base stations including at least one mobile base station, said method comprising the steps of:

collecting measurements of interference and load in said wireless communications
5 network;

processing said collected information to identify a resource for said mobile station such that said resource allocation minimizes a call drop rate; and

assigning said resource to said mobile station.

10 13. The method of claim 12, wherein said call drop rate ensures that a resource will not be assigned to said mobile station if a likelihood that allocating said resource to said mobile station will cause another mobile station to be dropped exceeds a predefined threshold.

14. A system for allocating a resource to a mobile station in a wireless communications network having at least one mobile base station, said system comprising:

a memory for storing computer readable code; and

a processor operatively coupled to said memory, said processor configured to:

collect measurements of interference and load in said wireless communications network, wherein said collected measurements include nominal resource availability information and measured resource availability information;

process said collected information to identify a resource for said mobile station;

and

assign said resource to said mobile station.

25 15. The system of claim 14, wherein said measurements are collected from both said mobile station and said base stations.

16. The system of claim 14, wherein said nominal resource availability information provides a measure of the load on said wireless communications network.

17. The system of claim 14, wherein said measured resource availability information provides a measure of the interference on said wireless communications network.

18. The system of claim 14, wherein said nominal resource availability is a nominal capacity value for each band on said network less the number of users on said band.

19. A system for allocating a resource to a mobile station in a wireless communications network having a plurality of base stations including at least one mobile base station, said system comprising:

a memory for storing computer readable code; and

a processor operatively coupled to said memory, said processor configured to:

collect measurements of interference and load in said wireless communications network, wherein said collected measurements include received power measurements from neighboring base stations;

process said collected information to identify a resource for said mobile station;

and

assign said resource to said mobile station.

20. The system of claim 19, wherein said power measurements are received from said neighboring base stations on a beacon channel.

21. The system of claim 19, wherein said received power measurements provide an indication of the distance to a neighboring base station.

22. The system of claim 19, wherein said measurements are collected from both said mobile station and said base stations.

23. A system for allocating a resource to a mobile station in a wireless communications network having a plurality of base stations including at least one mobile base station, said system comprising:

a memory for storing computer readable code; and
 a processor operatively coupled to said memory, said processor configured to:
 collect measurements of interference and load in said wireless communications
 network, wherein said collected measurements include predicted new load information;
 process said collected information to identify a resource for said mobile station;
 and
 assign said resource to said mobile station.

24. The system of claim 23, wherein said predicted new load, $\mu_{l,i}^D$, is computed as
 follows:

$$\mu_{l,i}^D = p_{l,i}^D \sum_{k=1}^K \lambda_k^D .$$

25. A system for allocating a resource to a mobile station in a wireless
 communications network having a plurality of base stations including at least one mobile base
 station, said system comprising:

collecting measurements of interference and load in said wireless communications
 network;

processing said collected information to identify a resource for said mobile station
 such that said resource allocation minimizes a call drop rate; and

assigning said resource to said mobile station.

26. The system of claim 25, wherein said call drop rate ensures that a resource will
 not be assigned to said mobile station if a likelihood that allocating said resource to said mobile
 station will cause another mobile station to be dropped exceeds a predefined threshold.

ABSTRACT

A distributed dynamic channel allocation algorithm is disclosed for a multi-carrier CDMA cellular system having at least one mobile base station. The disclosed distributed dynamic channel allocation algorithm used channel power measurements from both the requesting mobile station and the mobile base station attempting to allocate an available resource to the mobile station. The distributed dynamic channel allocation algorithm attempts to allocate the best available resource for the requesting mobile station, in terms of interference, while minimizing the amount of interruption that the allocated resource may cause to existing connections in neighboring cells. Thus, the distributed dynamic channel allocation algorithm follows a "least-interference, least-interruption" strategy. The distributed dynamic channel allocation algorithm of the present invention is load balancing, since it tends to assign new resources to mobile base station with lighter loads. Due to the mobility of the mobile base station, a mobile base station can cause interference to mobiles connected to another close-by mobile base station. The uplink and downlink channels are not paired and can be independently assigned to requesting mobile stations. A dynamic channel allocation process assigns resources to new mobile stations, while a dynamic channel allocation process assigns a new resource to an existing mobile station. The dynamic channel allocation process (new mobile) and dynamic channel allocation process (new resource for existing mobile) process collected measurement information on network interference and load conditions, and assign a resource to a requesting mobile station in an optimum manner.

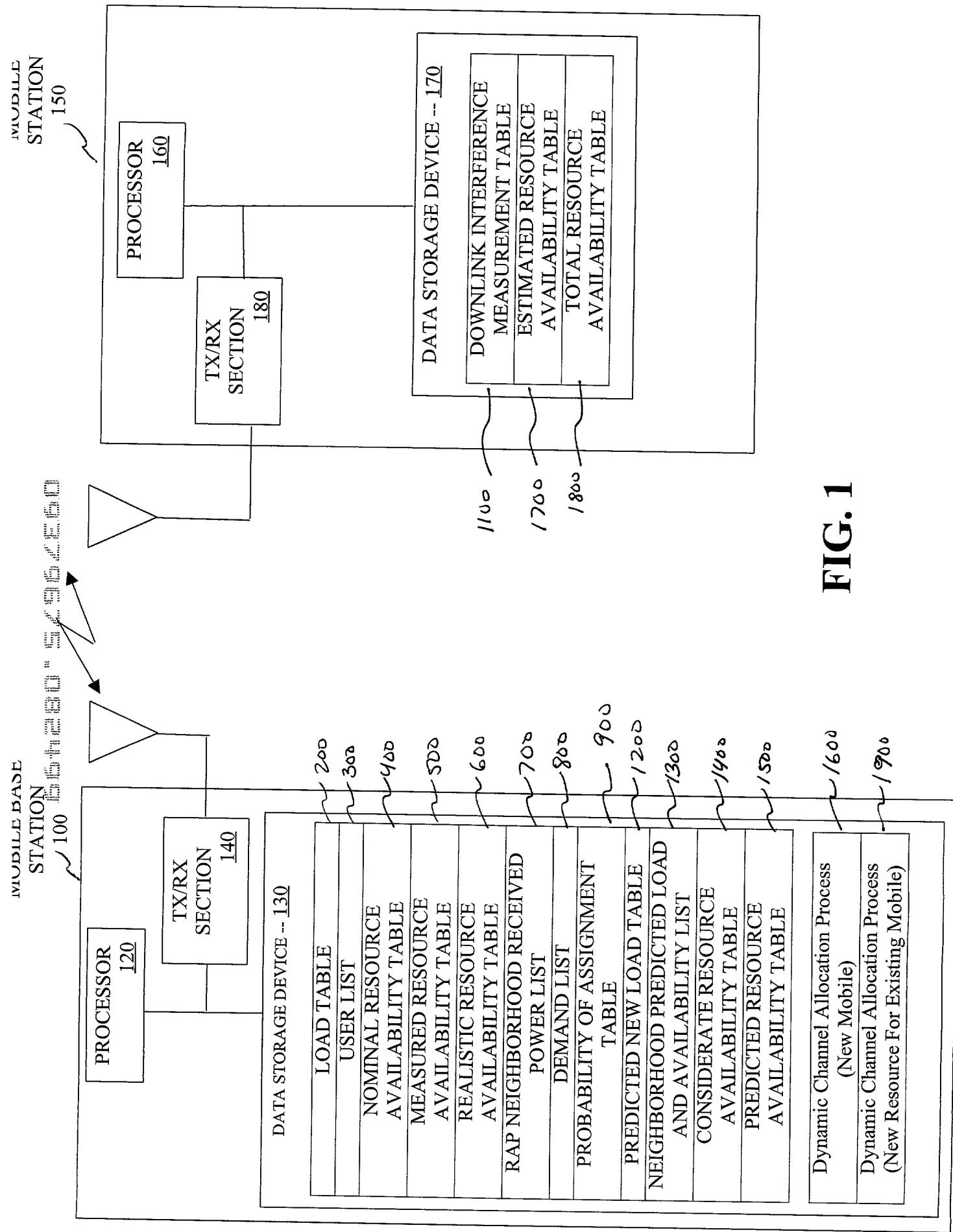


FIG. 1

200

ACTUAL LOAD TABLE FOR R_i			
DOWNLINK		UPLINK	
BAND	LOAD	BAND	LOAD
B_1^D	$m_{1,i}^D$	B_1^U	$m_{1,i}^U$
B_2^D	$m_{2,i}^D$	B_2^U	$m_{2,i}^U$
...
B_L^D	$m_{L,i}^D$	B_L^U	$m_{L,i}^U$

FIG. 2

300

ACTUAL USER LIST FOR R_i								
MOBILE ID	DOWNLINK				UPLINK			
	B_1^D	B_2^D	...	B_L^D	B_1^U	B_2^U	...	B_L^U
M_1	$C_{1,1}^{i,D}$	$C_{1,2}^{i,D}$	...	$C_{1,L}^{i,D}$	$C_{1,1}^{i,U}$	$C_{1,2}^{i,U}$	...	$C_{1,L}^{i,U}$
M_2	$C_{2,1}^{i,D}$	$C_{2,2}^{i,D}$	...	$C_{2,L}^{i,D}$	$C_{2,1}^{i,U}$	$C_{2,2}^{i,U}$	...	$C_{2,L}^{i,U}$
...			
M_K	$C_{K,1}^{i,D}$	$C_{K,2}^{i,D}$	...	$C_{K,L}^{i,D}$	$C_{K,1}^{i,U}$	$C_{K,2}^{i,U}$	...	$C_{K,L}^{i,U}$

FIG. 3

NOMINAL RESOURCE AVAILABILITY TABLE 400 FOR R_i			
DOWNLINK		UPLINK	
BAND	AVAIL.	BAND	AVAIL.
B_1^D	$a_{1,i}^{D,nom}$	B_1^U	$a_{1,i}^{U,nom}$
B_2^D	$a_{2,i}^{D,nom}$	B_2^U	$a_{2,i}^{U,nom}$
...
B_L^D	$a_{L,i}^{D,nom}$	B_L^U	$a_{L,i}^{U,nom}$

FIG. 4

MEASURED RESOURCE AVAILABILITY TABLE 500 FOR R_i			
DOWNLINK		UPLINK	
BAND	AVAIL.	BAND	AVAIL.
B_1^D	$a_{1,i}^{D,mrd}$	B_1^U	$a_{1,i}^{U,mrd}$
B_2^D	$a_{2,i}^{D,mrd}$	B_2^U	$a_{2,i}^{U,mrd}$
...
B_L^D	$a_{L,i}^{D,mrd}$	B_L^U	$a_{L,i}^{U,mrd}$

FIG. 5

REALISTIC RESOURCE AVAILABILITY TABLE 600 FOR R_i			
DOWNLINK		UPLINK	
BAND	AVAIL.	BAND	AVAIL.
B_1^D	$a_{1,i}^{D,real}$	B_1^U	$a_{1,i}^{U,real}$
B_2^D	$a_{2,i}^{D,real}$	B_2^U	$a_{2,i}^{U,real}$
...
B_L^D	$a_{L,i}^{D,real}$	B_L^U	$a_{L,i}^{U,real}$

FIG. 6

RAP Neighborhood Received Power List 700 for R_i	
RAP ID	Received Power Level
R_{i1}	$P_{i \leftarrow 1}$
R_{i2}	$P_{i \leftarrow 2}$
...	...
R_{iJ}	$P_{i \leftarrow J}$

FIG. 7

DEMAND LIST 800 FOR R_i		
MOBILE ID	# OF REQUESTED RESOURCES	LOCATION IN QUEUE
M_1	λ_1^D, λ_1^U	X_1
M_2	λ_2^D, λ_2^U	X_2
...
M_K	λ_K^D, λ_K^U	X_K

FIG. 8

PROBABILITY OF ASSIGNMENT TABLE 900 FOR R_i			
DOWNLINK		UPLINK	
BAND	AVAIL.	BAND	AVAIL.
B_1^D	$p_{1,i}^D$	B_1^U	$p_{1,i}^U$
B_2^D	$p_{2,i}^D$	B_2^U	$p_{2,i}^U$
...
B_L^D	$p_{L,i}^D$	B_L^U	$p_{L,i}^U$

FIG. 9

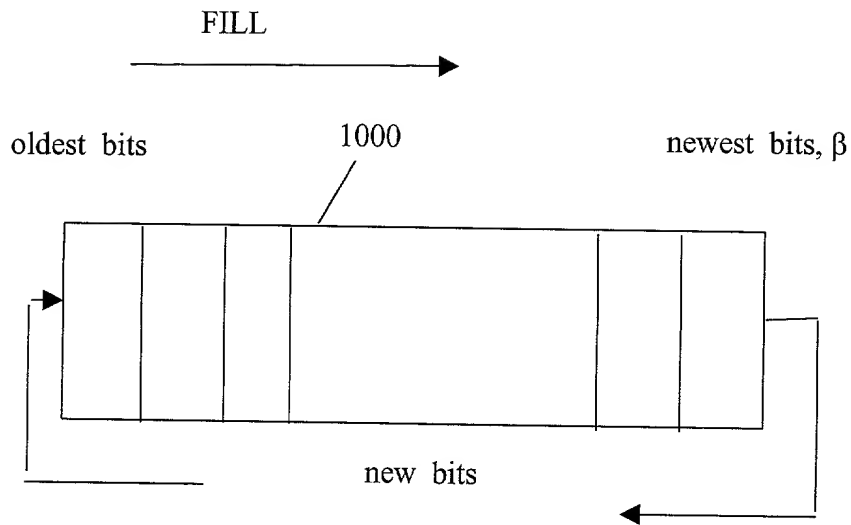


FIG. 10

MOBILE DOWNLINK INTERFERENCE MEASUREMENT TABLE 1100	
BAND	MEASURED INTERFERENCE LEVEL
B_1^D	$I_{1,k}^D$
B_2^D	$I_{2,k}^D$
\dots	\dots
B_L^D	$I_{L,k}^D$

FIG. 11

PREDICTED NEW LOAD TABLE 1200 FOR R_i			
DOWNLINK		UPLINK	
BAND	PREDICTED LOAD	BAND	PREDICTED LOAD
B_1^D	$\mu_{1,i}^D$	B_1^U	$\mu_{1,i}^U$
B_2^D	$\mu_{2,i}^D$	B_2^U	$\mu_{2,i}^U$
\dots	\dots	\dots	\dots
B_L^D	$\mu_{L,i}^D$	B_L^U	$\mu_{L,i}^U$

FIG. 12

RAP Neighborhood Predicted Load and Availability List 1300 for R_i		
RAP ID	Predicted Load	Real Availability
R_{i1}	$\mu_{l,i1}^D, \mu_{l,i1}^U \forall l$	$a_{l,i1}^{D,real}, a_{l,i1}^{U,real} \forall l$
R_{i2}	$\mu_{l,i2}^D, \mu_{l,i2}^U \forall l$	$a_{l,i2}^{D,real}, a_{l,i2}^{U,real} \forall l$
...
R_{iJ}	$\mu_{l,iJ}^D, \mu_{l,iJ}^U \forall l$	$a_{l,iJ}^{D,real}, a_{l,iJ}^{U,real} \forall l$

FIG. 13

CONSIDERATE RESOURCE AVAILABILITY TABLE 1400 FOR R_i			
DOWNLINK		UPLINK	
BAND	AVAIL.	BAND	AVAIL.
B_1^D	$a_{1,i}^{D,con}$	B_1^U	$a_{1,i}^{U,con}$
B_2^D	$a_{2,i}^{D,con}$	B_2^U	$a_{2,i}^{U,con}$
...
B_L^D	$a_{L,i}^{D,con}$	B_L^U	$a_{L,i}^{U,con}$

FIG. 14

PREDICTED RESOURCE AVAILABILITY TABLE 1500 FOR R_i			
DOWNLINK		UPLINK	
BAND	AVAIL.	BAND	AVAIL.
B_1^D	$a_{1,i}^{D,pred}$	B_1^U	$a_{1,i}^{U,pred}$
B_2^D	$a_{2,i}^{D,pred}$	B_2^U	$a_{2,i}^{U,pred}$
...
B_L^D	$a_{L,i}^{D,pred}$	B_L^U	$a_{L,i}^{U,pred}$

FIG. 15

Dynamic Channel Allocation
Process (New Mobile)

1600

MOBILE STATION M_K BROADCASTS A REQUEST FOR A
RESOURCE ALLOCATION

1605

MOBILE BASE STATIONS RESPOND WITH THEIR ID'S AND
RECEIVED POWER LEVELS DUE TO MOBILE

1610

MOBILE BASE STATIONS NORMALIZE POWER
MEASUREMENTS

1615

MOBILE STATION RESPONDS TO MOBILE BASE STATIONS IN
RANGE WITH LIST OF RAP IDS, AMOUNT OF REQUIRED
RESOURCES, AND DOWNLINK INTERFERENCE
MEASUREMENT TABLE

1620

MOBILE FORMS A TABLE OF POTENTIAL MOBILE BASE
STATIONS AND CORRESPONDING RECEIVED POWER
LEVELS

1625

MOBILE STATIONS NORMALIZE POWER MEASUREMENTS

1630

MOBILE BASE STATIONS RESPOND TO M_K WITH MOST
RECENT PREDICTED RESOURCE AVAILABILITY TABLES, THE
LOCATION OF M_K IN QUEUES AND NORMALIZED RECEIVED
POWER LEVELS

1635

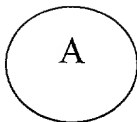
MOBILE M_K FORMS MOBILE-ESTIMATED AVAILABILITY
TABLES FOR EACH MOBILE BASE STATION AND
TOTAL AVAILABILITY TABLE

1640

A

TO FIG.
16B

FIG. 16A



FROM
FIG. 16A

MOBILE M_K PICKS MOBILE BASE STATION(S) WHICH CAN
PROVIDE ALL REQUIRED RESOURCES ON BOTH
UPLINK AND DOWNLINK 1645

REDUCE RESOURCE REQUIREMENTS
BY ONE 1655

DOES A MOBILE BASE STATION
SATISFY ALL RESOURCES 1648

YES

MOBILE M_K PICKS MOBILE BASE
STATION WITH HIGHEST AGGREGATE
AVAILABILITY 1650

ANNOUNCE MOBILE BASE STATION
SELECTION 1660

ALL OTHER MOBILE BASE STATIONS
DROP M_K OFF THEIR QUEUES AND
UPDATE AVAILABILITY TABLES 1665

SUCCESSFUL BASE STATION KEEPS
 M_K IN QUEUE UNTIL ALL REQUESTS
AHEAD OF M_K ARE PROCESSED AND
THEN ALLOCATES M_K REQUIRED
RESOURCES 1670

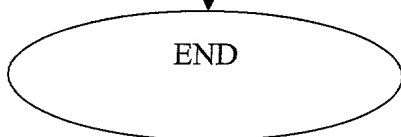


FIG. 16B

MOBILE-ESTIMATED RESOURCE AVAILABILITY TABLE 1700 FOR R_i BY M_k			
DOWNLINK		UPLINK	
BAND	AVAIL.	BAND	AVAIL.
B_1^D	$a_{1,i}^{D,MobEst}$	B_1^U	$a_{1,i}^{U,MobEst}$
B_2^D	$a_{2,i}^{D,MobEst}$	B_2^U	$a_{2,i}^{U,MobEst}$
...
B_L^D	$a_{L,i}^{D,MobEst}$	B_L^U	$a_{L,i}^{U,MobEst}$

FIG. 17

MOBILE TOTAL RESOURCE AVAILABILITY TABLE 1800 FOR M_k			
DOWNLINK		UPLINK	
RAP	AVAIL.	RAP	AVAIL.
R_1	$a_i^{D,total}$	R_1	$a_i^{U,total}$
R_2	$a_i^{D,total}$	R_2	$a_i^{U,total}$
...
R_N	$a_i^{D,total}$	R_N	$a_i^{U,total}$

FIG. 18

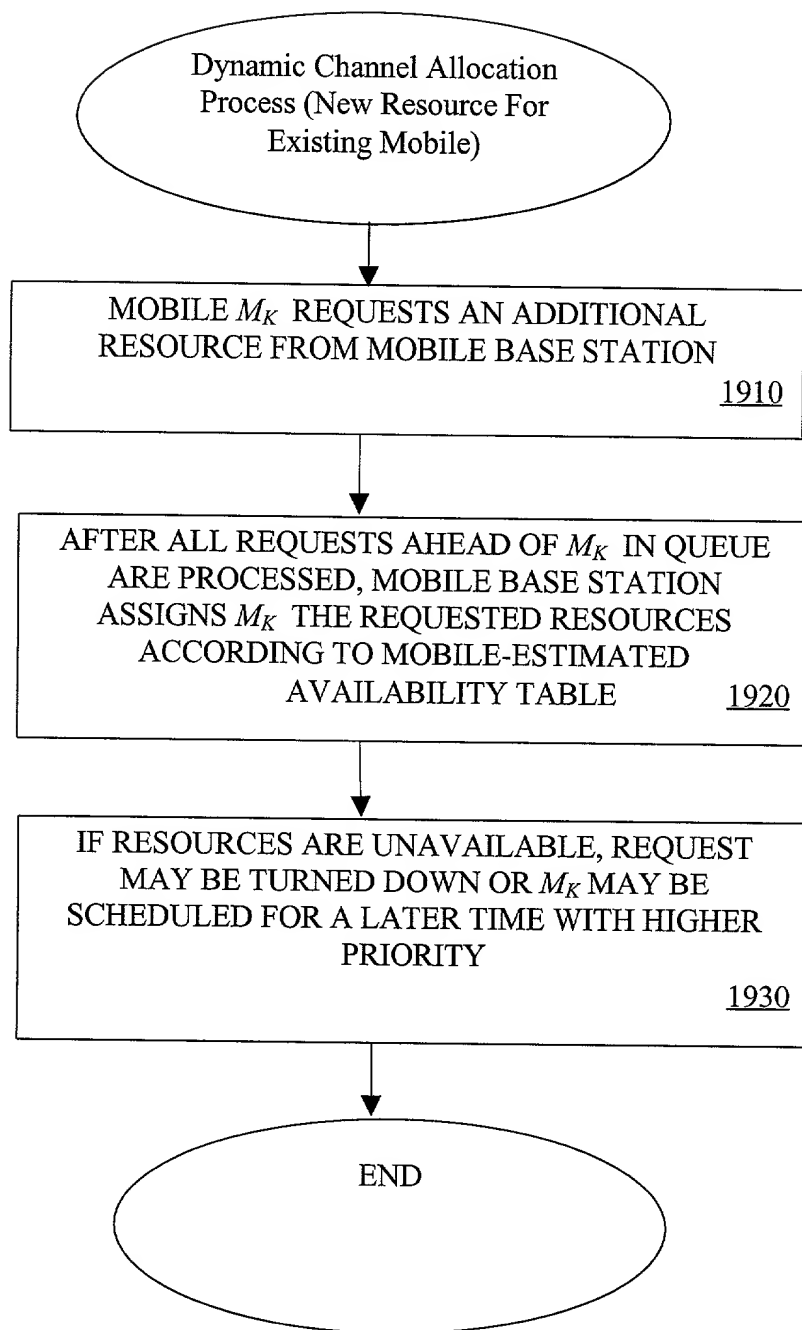


FIG. 19

IN THE UNITED STATES
PATENT AND TRADEMARK OFFICE

Declaration and Power of Attorney

As the below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled **DISTRIBUTED DYNAMIC CHANNEL ALLOCATION TECHNIQUE FOR MULTI-CARRIER CDMA CELLULAR SYSTEMS WITH MOBILE BASE STATIONS**, the specification of which is attached hereto.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by an amendment, if any, specifically referred to in this oath or declaration.

I acknowledge the duty to disclose all information known to me which is material to patentability as defined in Title 37, Code of Federal Regulations, 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

None

I hereby claim the benefit under Title 35, United States Code, 119(e) of any United States provisional application(s) listed below:

None

I hereby claim the benefit under Title 35, United States Code, 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, 112, I acknowledge the duty to disclose all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

None

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

661290" 54967E60

I hereby appoint the following attorney(s) with full power of substitution and revocation, to prosecute said application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent and Trademark Office connected therewith:

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I hereby appoint the attorneys on ATTACHMENT A as associate attorneys in the aforementioned application, with full power solely to prosecute said application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent and Trademark Office connected with the prosecution of said application. No other powers are granted to such associate attorneys and such associate attorneys are specifically denied any power of substitution or revocation.

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